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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G02B 5/13, E01F 9/06

A1

(11) International Publication Number: WO 98/00737

(43) International Publication Date: 8 January 1998 (08.01.98)

(21) International Application Number: PCT/IL97/00216

(22) International Filing Date: 26 June 1997 (26.06.97)

(30) Priority Data:
118759 30 June 1996 (30.06.96) IL

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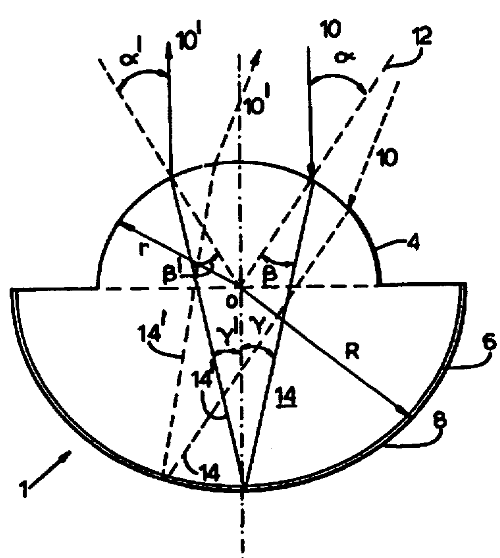
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: RETROREFLECTIVE LENTICULAR ELEMENTS



(57) Abstract

There is provided an integral array of retroreflective lenticular elements (1), each of which elements (1) being based on an imaginary, substantially prismatic body of a polygonal cross section and has two convexly curved end surfaces (4, 6), wherein the ratio of the angular range of retroreflection in the elevational plane thereof is predeterminable by the geometry of the cross section. There is also provided an integral array (2) of retroreflective lenticular elements (1) wherein the retroreflective lenticular elements (1) are arrayed in such a way that their convexly curved end surfaces (4, 6) constitute a tesselation pattern, with the major surfaces of the array (2) substantially fully tesselated.

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RETROREFLECTIVE LENTICULAR ELEMENTS

Background of the Invention

The present invention relates to retroreflective lenticular elements, more particularly to an integral array of such units.

The phenomenon of reflection, i.e., the property of certain optical components to reflect beams of light back to their source, regardless, within limits, of their angle of incidence, has been long known. Basically, there exist at least two different types of retroreflectors in practical use: the first type, in which three reflective planar surfaces intersect each other at 90°, forming a "corner" (hence, "corner cube"), and the second type, which is lens-shaped and has a convex, transparent surface on the side facing the light source, and a convex, reflective rear side. As the individual elements of either type are rather small, they are grouped to form arrays of optional size and shape.

While retroreflectors are also used for various scientific and engineering purposes, their most widespread use is as road markings where, as the well-known "cat's eyes," i.e., arrays of more or less closely packed single elements mounted along the dividing line between adjacent road lanes, or as various markings along the road edge, their function is to "light up" when hit by light from motorists' headlights.

Today, cat's eyes are made from both types of retroreflectors, corner cubes as well as lenticular. Both types, however, suffer from significant drawbacks. Corner cube cat's eyes, while making efficient use of the surface area of the array, have a very limited range of angles of incidence over which light is indeed retroreflected. Existing lenticular cat's eyes, although having a larger angular

range, return only a relatively low percentage of the incident light, i.e., are of low luminosity. This is due to the inefficient design of these lenticular arrays which, in order to reduce costs, often disregards the optical laws ruling these devices.

A further serious disadvantage of prior art cat's eyes resides in the fact that their lenticular arrays have the same angular range of effective retroreflection in the azimuthal plane as they have in the elevational plane. Conditions on the road, however, often require a larger angular range in the azimuthal plane than in the elevational plane, due to the fact that the differences in height above the road surface of the headlights of different vehicles (as well as of their drivers' eyes) is small as compared with the minimum distance at which cat's eyes must become effectively perceptible and, therefore, a small angular range of effective retroreflection will cover whatever differences exist between the above heights. However, at any distance, the possible lateral offset of a vehicle from the elevational (vertical) median plane of the array is liable to be much larger and can be covered only by a relatively large angular range of retroreflection.

Yet prior art cat's eyes, such as proposed by U.S. Patents 1,934,492; RE 19070 and 3,963,309, completely ignore this fact, the recognition of which, as will become obvious further below, permits the luminosity of these devices to be substantially increased without increasing their height dimension which, at least with roadbed-mounted cat's eyes, is strictly limited.

Summary of the Invention

It is thus one of the objects of the present invention to provide a one-piece retroreflective lenticular array that, over a wide range of angles of incidence, possesses a high degree of retroreflectivity, i.e., is of high luminosity.

It is a further object of the invention to provide a retroreflective array of lenticular elements in which the ratio of the angular range of retroreflection in the azimuthal plane of the array to the angular range of retroreflection in the elevational plane thereof can be predetermined by an appropriate choice of the geometry of these elements.

According to the invention, these objects are achieved by providing an integral array of retroreflective lenticular elements, each of which elements is based on an imaginary, substantially prismatic body of a polygonal cross-section and has two convexly curved end surfaces, wherein the ratio of the angular range of retroreflection in the azimuthal plane of said array to the angular range of retroreflection in the elevational plane thereof is predeterminable by the geometry of said cross-section.

The invention further provides an integral array of retroreflective lenticular elements, each of which elements is based on an imaginary, substantially prismatic body of a polygonal cross-section and has two convexly curved end surfaces, wherein said retroreflective lenticular elements are arrayed in such a way that their convexly curved end surfaces constitute a tesselation pattern, with the major surfaces of said array being substantially fully tesselated.

The invention will now be described in connection with certain preferred embodiments with reference to the following illustrative figures so that it may be more fully understood.

With specific reference now to the figures in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

Description of the Drawings

Fig. 1 is a schematic view of a single element of the array according to the invention, explaining the optics thereof;

Fig. 2 shows a prior art array comprising glass elements embedded in a plastic disc;

Fig. 3 represents an array of the same size according to the invention;

Fig. 4 illustrates the "shaving," according to the invention, of a basic element such as that shown in Fig. 1;

Fig. 5 shows an array for roadbed-mounted cat's eyes comprised of elements constituted by "compressed," irregular hexagons;

Fig. 6 represents the prior art arrays of Fig. 2, as mounted in a metal or plastic housing;

Fig. 7 illustrates a portable road sign, e.g., for roads under repair;

Fig. 8 is a section, to a larger scale, through one of the cat's eyes type strips that are an integral part of the road sign of Fig. 7;

Fig. 9 shows arrays of cat's eyes in a mount designed for the elements of the arrays to project sufficiently to be wiped clean by the tires passing over them:

Fig. 10 is an elevation of an array of Fig. 9, showing a circumferential rim for sealing off the socket in the mount;

Fig. 11 is a perspective view of a warning cone for use on roads under repair;

Fig. 12 depicts the developed skirt of the cone of Fig. 11, made of flexible, plastic, transparent material and constituting the array of lenticular elements;

Fig. 13 is an enlarged view in cross-section along plane XIII-XIII of the skirt of Fig. 12;

Fig. 14 is a perspective view of a trough-like road marker pole carrying strips of lenticular elements according to the invention:

Fig. 15 is a cross-sectional view, to an enlarged scale, of the array of lenticular elements of Fig. 14;

Fig. 16 is a perspective view of a marker for safety rails made of a plastic, transparent T-profile, the upright web of which is constituted by an array comprising rows of retroreflective elements, which rows are alternatingly retroreflective towards both sides;

Fig. 17 is an enlarged cross-sectional view of the array of Fig. 16, showing the staggered and alternating arrangement of the lenticular units:

Fig. 18 is a perspective view showing an alternative close-packing arrangement, in which the imaginary constituent prism is of a triangular cross-section:

Fig. 19 is a perspective view of the triangular prism of the arrangement of Fig. 18:

Fig. 20 illustrates another close-packing arrangement in which the imaginary constitutent prism is of a rectangular cross-section:

Fig. 21 is a perspective view of the rectangular prism of Fig. 20, and

Fig. 22 represents an embodiment in which the reflective coating is subdivided into sections causing the reflected rays to be of different colors as a function of the angle of incidence.

Description of the Preferred Embodiment

Referring now to the drawings, there is seen in Fig. 1 a schematic view of one of the lenticular elements of the array according to the invention. Optically, the per se known element 1 is a katadioptric device, i.e., a device based on a combination of refraction and reflection. Refraction is effected by the spherical surface 4, having a radius of curvature r, and reflection is provided by spherical surface 6 which is given a reflective coating 8 and has a radius of curvature R. Surface 4 and surface 6 have a common center of curvature 0. It is seen that an incoming light ray 10 hits surface 4 at an angle of incidence α and is refracted at that surface, including with the normal 12 an angle β which is determined by Snell's Law: $\sin \alpha/\sin \beta = n$, with n being the index of refraction of the material of which element 1 is made. The optical parameters of element 1 are such that the refracted ray 14 is brought to focus at surface 6, whence it is reflected by the reflective coating 8.

Reflection takes place by the simple laws of reflection, according to which the angle of reflection γ' is equal to the angle of incidence γ. Reflected ray 14', arriving at the inside of surface 4 at an angle of incidence $\beta' = \beta$, is again refracted and emerges from element 1 at an angle of emergence α'. As $\alpha' = \alpha$, emerging ray 10' is obviously parallel to incident ray 10. A similar situation obtains when the incident ray is oblique, as indicated by the dashed rays 10, 10'.

The above-mentioned optical parameters are determined according to the expression

$$R = \frac{r}{n - 1} \qquad (1)$$,

where

R = radius of curvature of surface 6;

r = radius of curvature of surface 4;

n = index of refraction of the material.

A further condition, already mentioned, is the coincidence of the respective centers of curvature 0. From this it is also clear that the vertex-to-vertex distance of element 1 is R + r.

While in the above explanations surfaces 4 and 6 were said to be spherical, embodiments are also envisaged with aspherical (e.g., paraboloidal or ellipsoidal) surfaces.

The present invention applies the principle of close packing of the lenticular elements, a principle which, in its application to the Euclidean plane, is also known as tesselation or gap-less tiling. This principle clearly emerges from a comparison of Fig. 2, which shows a prior art cat's eyes array 2 in the form of glass cylinders mounted in a plastic disc 5, and Fig. 3, which represents a cat's eyes array according to the invention. It is obvious that close packing, by eliminating the "dead" areas in an array, significantly increases the specific reflective yield of the array, i.e., the reflective yield per unit area.

Close packing is achieved by "crowding together" or "compacting" elements 1, such as shown in Fig. 1, making them interpenetrate. The most obvious shapes produced by such "compaction" would be hexagons, as these polygons can "tile" a surface without leaving gaps, while still being fairly close in shape to a circle. The "compacting process" can be best visualized by assuming the array (which in reality, it should be remembered, is an integral molding) to be compounded of a plurality of (imaginary) elements 1, marginal portions of which have been cut away as shown in Fig. 4, to produce an imaginary prismatic body.

While "shaving" obviously entails a certain loss in the angular range of retroreflection since beyond a certain angle of incidence, rays will no longer hit the reflective surface 6 and, therefore, will no longer be reflected by the latter, this loss, for a reason to be discussed presently, is quite immaterial and is more than offset by the above-mentioned advantages of close packing.

The initial assumption, referred to in conjunction with Fig. 1, namely, that incident rays are brought to focus at surface 6, is correct only within a certain range of angles of incidence α. Beyond that, due to spherical aberration of surface 4, rays no longer focus on surface 6; therefore retroreflection progressively deteriorates with increasing angles of incidence α. This, incidentally, is the reason why the above-mentioned "shaving off" of the marginal zones of element 1 is of no great importance: retroreflectivity in these zones is in any case greatly impaired.

This imperfection has, however, enabled the present invention to not only deliberately determine the angular range of retroreflection of the array in at least

one plane to fit demands in the field, but within that selected range, to significantly increase the luminosity of the array.

This is effected by modifying the cross-section of the imaginary prismatic element 1 seen in Figs. 3 and 4 from a regular hexagon to the irregular hexagon seen in Fig. 5. While this "compression" of elements 2 obviously reduces the angular range of retroreflection in the elevational (vertical) plane, it cuts away a large proportion of the less effective marginal zones and not only retains the central aea of elements 1 in which retroreflection is close to 100%, but enables the necessarily limited height of roadbed-mounted cat's eyes to accommodate, in the vertical direction, almost twice as many elements 1 as has the array of the same outside dimensions, but comprised of imaginary prisms having a cross-section of regular hexagons.

The major dimensions of elements 1 required to obtain an angular range of retroreflection adapted to conditions in the field are easily calculated, if these empirically determinable ranges are known, using the expression

$$D_{w,h} = 2R \sin\alpha_{a,e} \qquad (2)$$

where:

D_w = width (in the horizontal direction) of element 1;

D_h = height (in the vertical direction) of element 1;

R = radius of curvature of surface 6 (Fig. 1);

$\alpha_{a,e}$ = desired angular ranges of retroreflection (in the azimuthal and elevational planes, respectively).

First to be determined is R, using expression (1) and assuming r to be, say, 5 mm, with n being set as 1.625:

$$R = \frac{r}{1.625 - 1} = 8 \text{ mm} \quad .$$

Assuming the desired angular range of retroreflection in the azimuthal plane. α_a. to be 20°,

$$D_w = 2R \sin 20$$
$$= 5.8 \text{ mm} \quad .$$

For reasons explained earlier. the desired angular range of retroreflection in the elevational plane. α_e. can be much smaller. say. 10°. then

$$D_h = 2R \sin 10$$
$$= 2.8 \text{ mm} \quad .$$

Fig. 6 shows a prior art cat's eyes device for mounting on the roadbed. Mount 16. advantageously made of aluminum or of a tough plastic and having a stem 18 for anchoring in the roadbed. accommodates on each of its sides three of the cat's eyes array 2 shown in Fig. 2. If these three arrays were replaced with one array according to Fig. 5. the height of which equals the diameter of the discoid arrays 2 of Fig. 6 and the length of which is three times the diameter of one of these arrays 2. the surface area covered with lenticular elements 1 would increase by a factor of five.

Fig. 7 shows a portable road sign to be used on roads. e.g.. under repair. The road sign is made of a plastic. transparent panel 20 with which are integrally formed a number of strip-like. slanting arrays 2. Surrounding panel 20 is a rim 22 of a U-shaped cross-section designed to provide rigidity and mechanical

strength. Also integral with panel 20 are two legs 24 to be anchored in a heavy base plate 26 for stability.

Fig. 8 is a section, to a larger scale, through one of arrays 2.

Mount 16 in Fig. 9 accommodates two arrays 2, one on each side. Arrays 2 are cemented into sockets 28 of appropriate shape and size, with rims 30 sealing off sockets 28. Fig. 10 is a frontal view of the arrays 2, which are based on regular hexagons. The relative dimensions of arrays 2 and sockets 28 are such that the convex surfaces 4 of arrays 2 project beyond the slanting surfaces of mount 18 to a sufficient degree to be wiped clean by tires 32 passing over them (Fig. 9). It is also seen that, in this embodiment, the longitudinal axes 29 of the prismatic bodies are inclined relative to the plane defined by end surfaces 6 of array 2, which plane is advantageously realized by the bottom surface of socket 28.

Fig. 11 shows one of the plastic or rubber warning cones 34 used on roads under repair. Array 2 is in the form of a skirt 36 made of a flexible, transparent plastic sheet integral with elements 1, which can be wrapped about cone 34. Array 2 is developed in Fig. 12, showing also snap fasteners 38 for joining the edges of array 2. An enlarged, partial view of skirt 36, as seen in the direction of Arrow A, is shown in Fig. 13. Here, too, it is seen that axes 29 are inclined relative to a plane defined by end surfaces 6 or 4 of array 2.

Fig. 14 shows a road marker pole or stake 40 of a trough-like cross-section to which are applied, or with which are integral, strips consisting of arrays 2 of lenticular elements 1. The enlarged cross-sectional view of Fig. 15

shows an array 2 of lenticular elements 1. It is seen that the axes of elements 1 are parallel rather than radial relative to pole 40.

Fig. 16 represents a marker for safety rails and is made of a plastic, transparent T-profile 42, the vertical web of which is constituted by an array 2 comprising alternating rows a and b of elements 1, rows a being retroreflective towards side A and rows b toward side B.

Fig. 17 is a cross-sectional view to an enlarged scale of array 2 of Fig. 16. It is seen that rows a and b are laterally offset relative to a median plane of array 2, to facilitate application of reflective coating 8 by silk-screen or pad printing to each of rows a and b. Slots 44 facilitate attachment of T-profile 42 to the safety rails.

Fig. 18 is a perspective view showing an alternative close-packing arrangement in which the imaginary constituent element 1 is in the form of a prism of an equilateral triangular cross-section. The prism itself with its upper end surface 4 and its lower end surface 6 is seen in Fig. 19.

Fig. 20 illustrates yet another close-packing arrangement in which the imaginary constituent element 1 is in the form of a prism of a rectangular cross-section, with the prism itself shown in Fig. 21.

Fig. 22 represents an embodiment in which the reflective coating is subdivided into a central portion 46 and a peripheral, annular portion 48, with each of these portions having a different color, such as red and green. As a consequence, rays hitting element 1 at a small angle of incidence will be focused

on central section 46 and, therefore, will return as red rays, while rays impacting element 1 at a larger angle of incidence will be focused on annular section 48, thus being returned as green rays.

It will be evident to those skilled in the art that the invention is not limited to the details of the foregoing illustrated embodiments and that the present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

CLAIMS

1. An integral array of retroreflective lenticular elements, each of which elements is based on an imaginary, substantially prismatic body of a polygonal cross-section and has two convexly curved end surfaces, wherein the ratio of the angular range of retroreflection in the azimuthal plane of said array to the angular range of retroreflection in the elevational plane thereof is predeterminable by the geometry of said cross-section.

2. An integral array of retroreflective lenticular elements, each of which elements is based on an imaginary, substantially prismatic body of a polygonal cross-section and has two convexly curved end surfaces, wherein said retroreflective lenticular elements are arrayed in such a way that their convexly curved end surfaces constitute a tesselation pattern, with the major surfaces of said array being substantially fully tesselated.

3. The array as claimed in claim 1 or 2, wherein one of the end surfaces of said prismatic bodies serves as a positive lens, the other end surface being provided with a reflective coating.

4. The array as claimed in claim 1 or 2, wherein said convexly curved end surfaces are substantially spherical.

5. The array as claimed in claim 3, wherein the radii of curvature of said end surfaces serving as positive lenses are smaller than those of said end surfaces being provided with a reflective coating.

6. The array as claimed in claim 1 or 2, wherein the distance between the vertices of said convex end surfaces of each of said imaginary bodies is equal to the sum of the radii of curvature of said two convexly curved end surfaces.

7. The array as claimed in claim 1 or 2, wherein the cross-section of said imaginary prismatic body is a regular hexagon.

8. The array as claimed in claim 1 or 2, wherein the cross-section of said imaginary prismatic body is an irregular hexagon.

9. The array as claimed in claim 1 or 2, wherein the cross-section of said imaginary prismatic body is a triangle.

10. The array as claimed in claim 9, wherein said triangle is an equilateral triangle.

11. The array as claimed in claim 1 or 2, wherein the cross-section of said imaginary prismatic body is a rectangle.

12. The array as claimed in claim 1 or 2, wherein said array is an integral part of a portable road sign.

13. The array as claimed in claim 1 or 2, wherein said array is mounted in a socket of a mount attachable to a roadbed.

14. The array as claimed in claim 13, wherein said elements of said array project from said socket to a sufficient degree to be wiped clean by vehicle tires passing over them.

15. The array as claimed in claim 14, wherein said array is provided with a circumferential rim for sealing off said socket.

16. The array as claimed in claim 1 or 2, wherein said array is in the form of a skirt mountable on a warning cone for roads.

17. The array as claimed in claim 1 or 2, wherein said imaginary bodies are inclined relative to an imaginary plane defined by either one of the collective end surfaces of said bodies.

18. The array as claimed in claim 1 or 2, wherein said array is in the form of strips integral with, or attachable to, trough-like road marker poles.

19. The array as claimed in claim 18, wherein the axes of the elements of said array are parallel with each other.

20. The array as claimed in claim 1 or 2, wherein said array is an integral part of a T-profile, the vertical web of which is at least partly constituted by said array.

21. The array as claimed in claim 20, wherein said array is constituted of alternating rows of elements, one of which alternating rows is retroreflective towards one side of said web, the other towards the other side of said web.

22. The array as claimed in claim 21, wherein said alternating rows are mutually laterally offset relative to a median plane of said array.

23. The array as claimed in claim 3, wherein said reflective coating is subdivided into a central section and a peripheral, annular section, said sections being of different colors, causing reflected rays to be of different colors.

Fig.1.

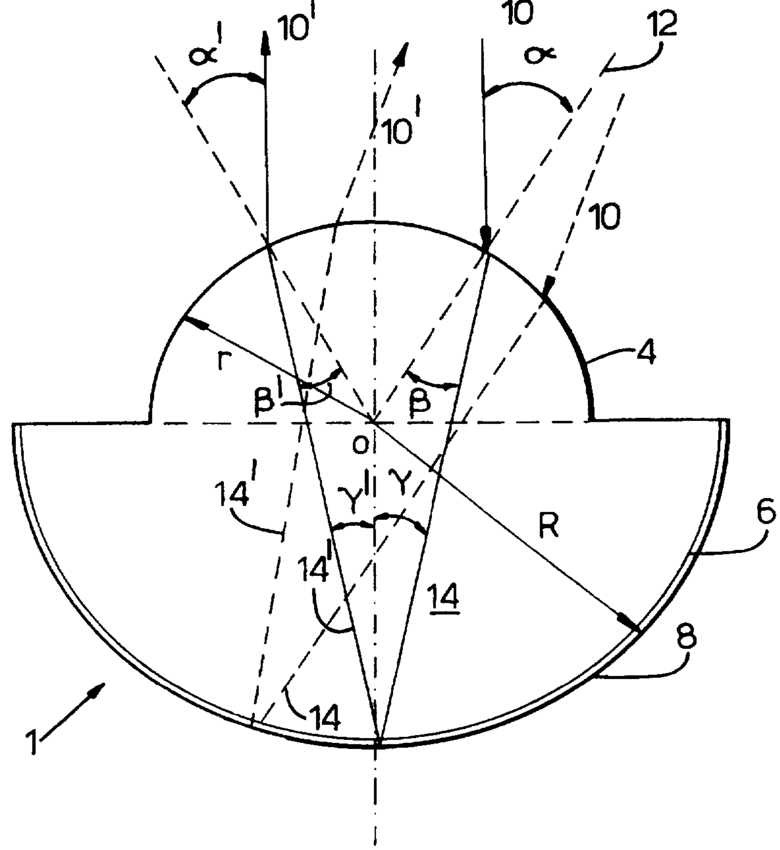


Fig.2.

PRIOR ART

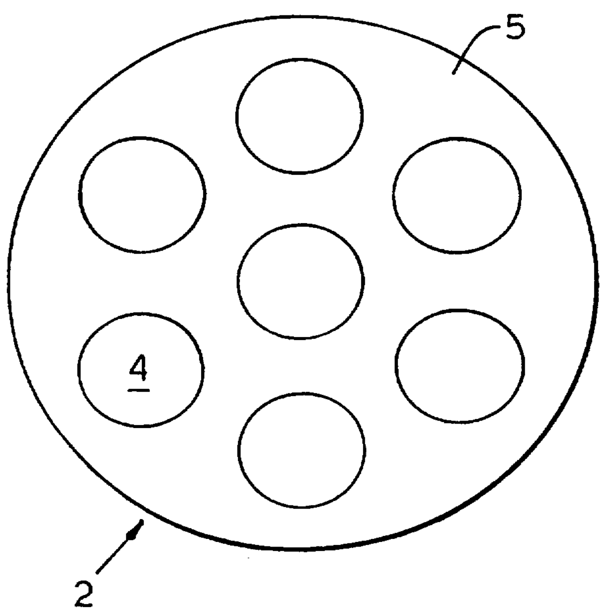


Fig.3.

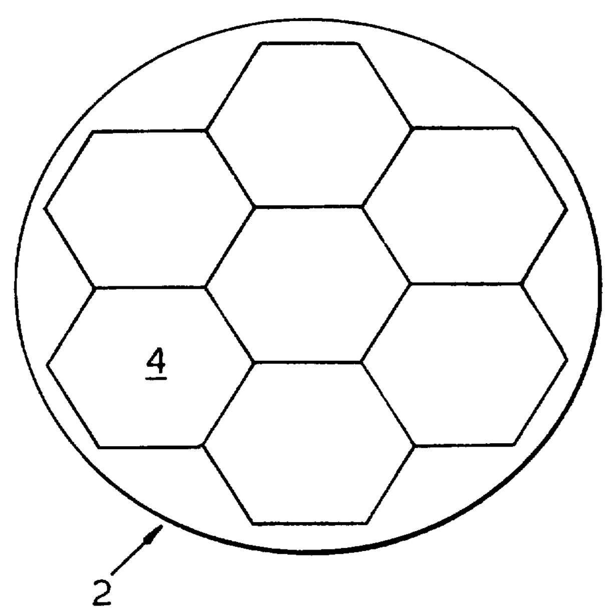


Fig.4.

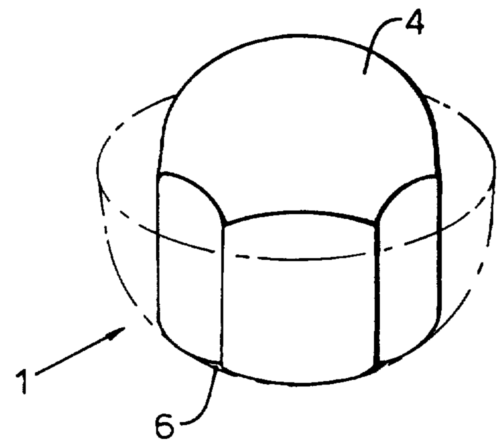


Fig.5.

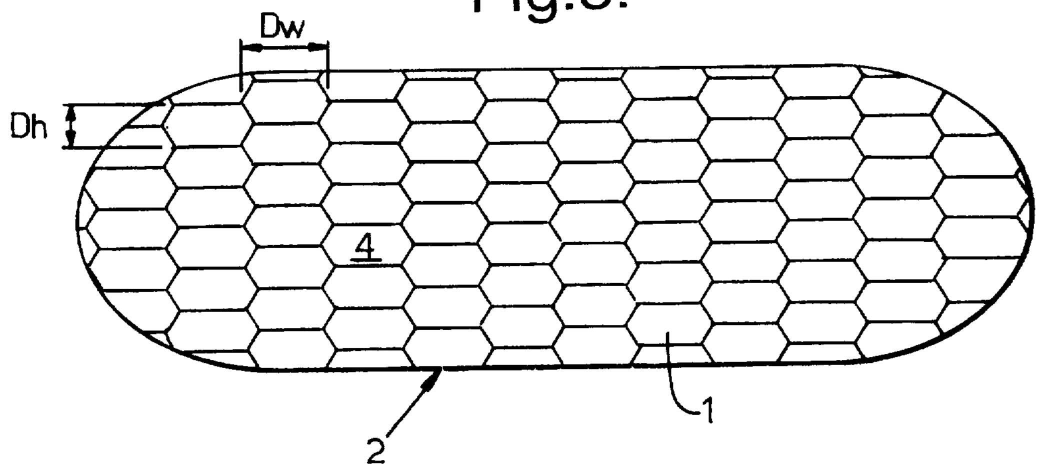


Fig.6.

PRIOR ART

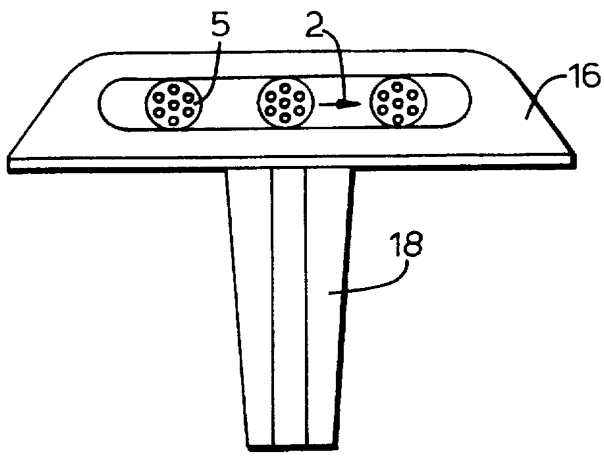


Fig.7.

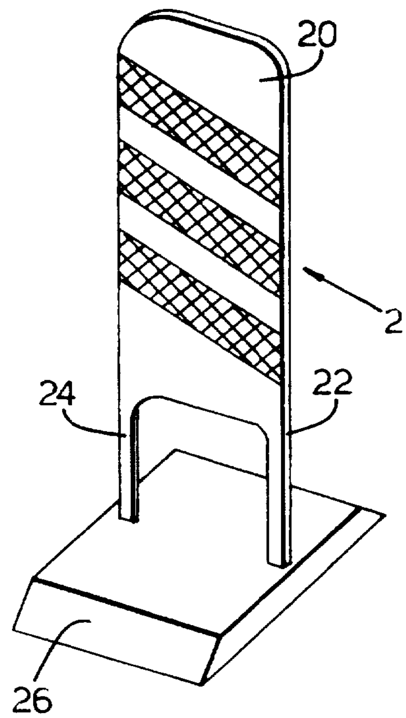


Fig.8.

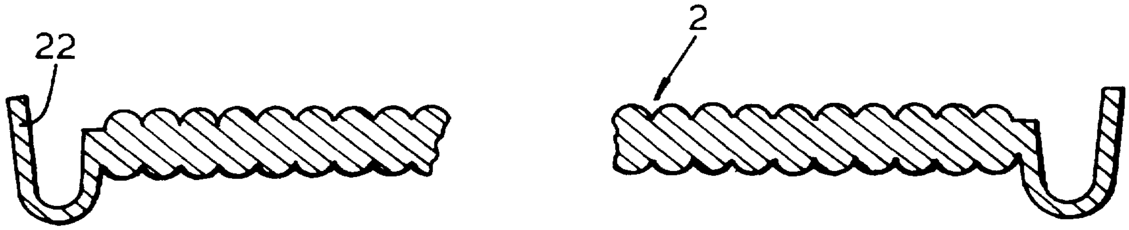


Fig.9.

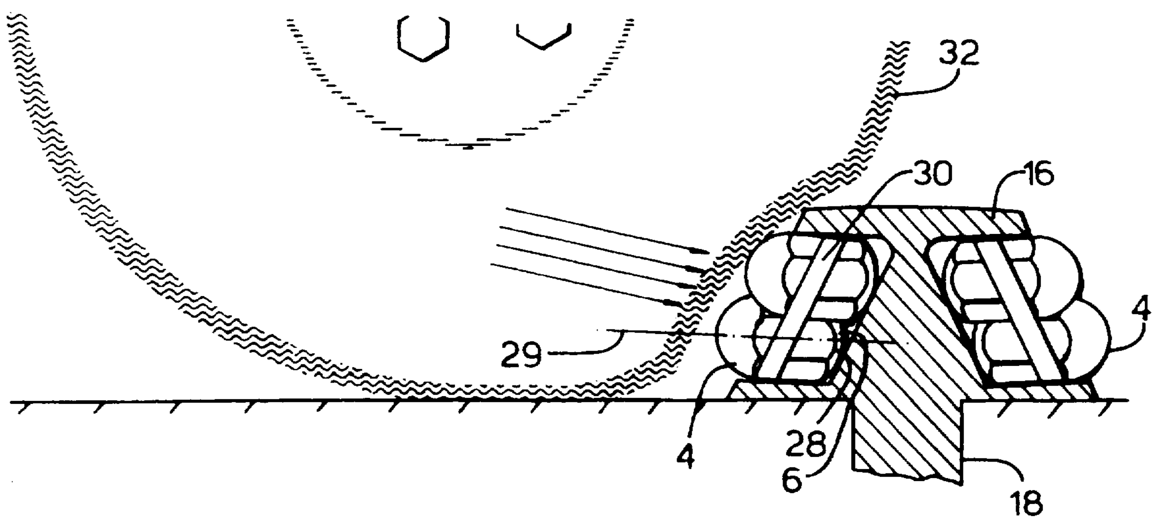


Fig.10.

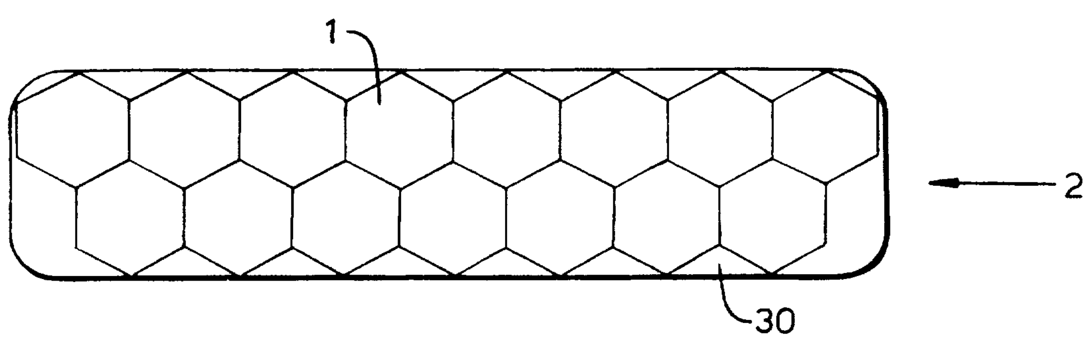


Fig.11.

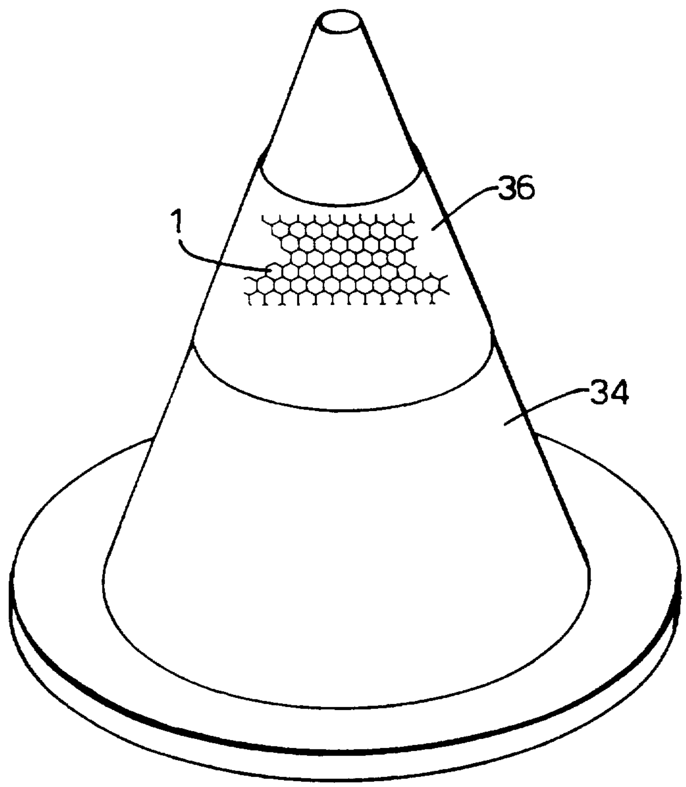


Fig.13.

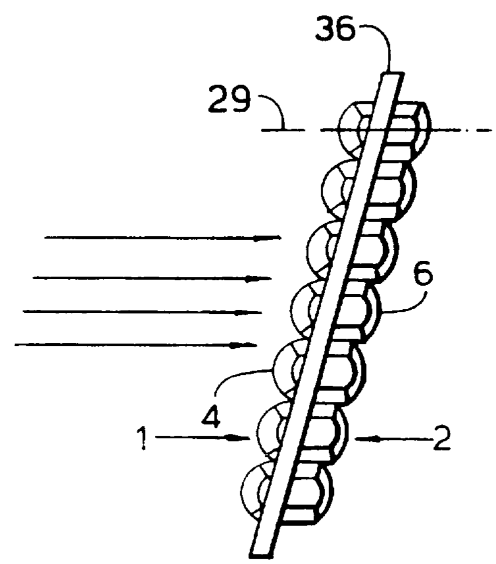


Fig.12.

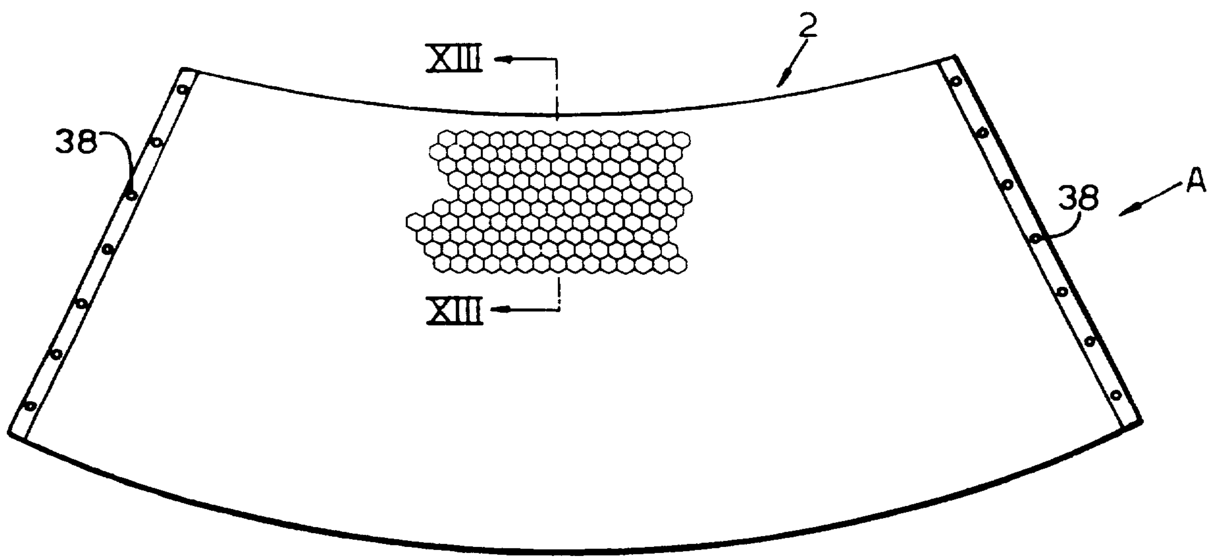


Fig.14.

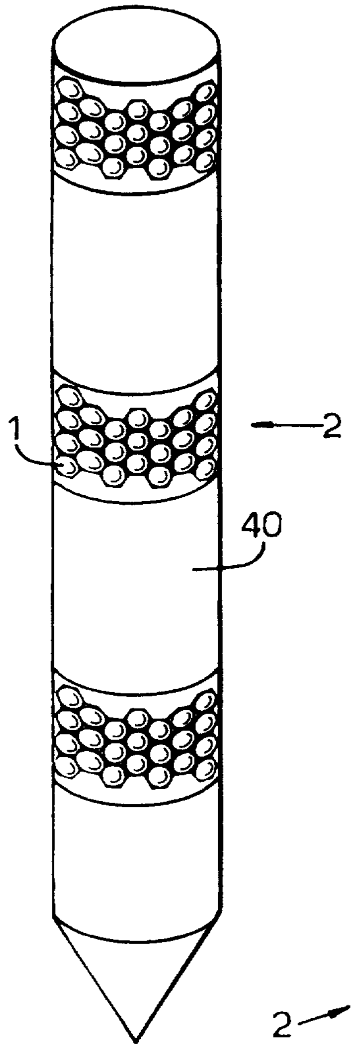


Fig.17.

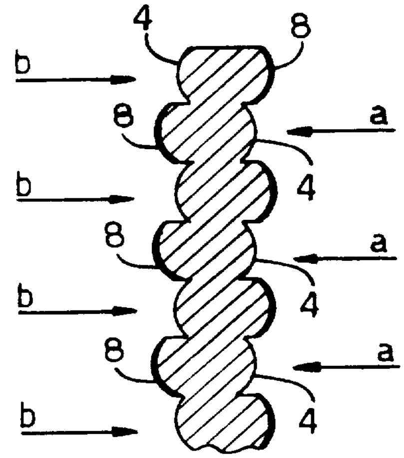


Fig.16.

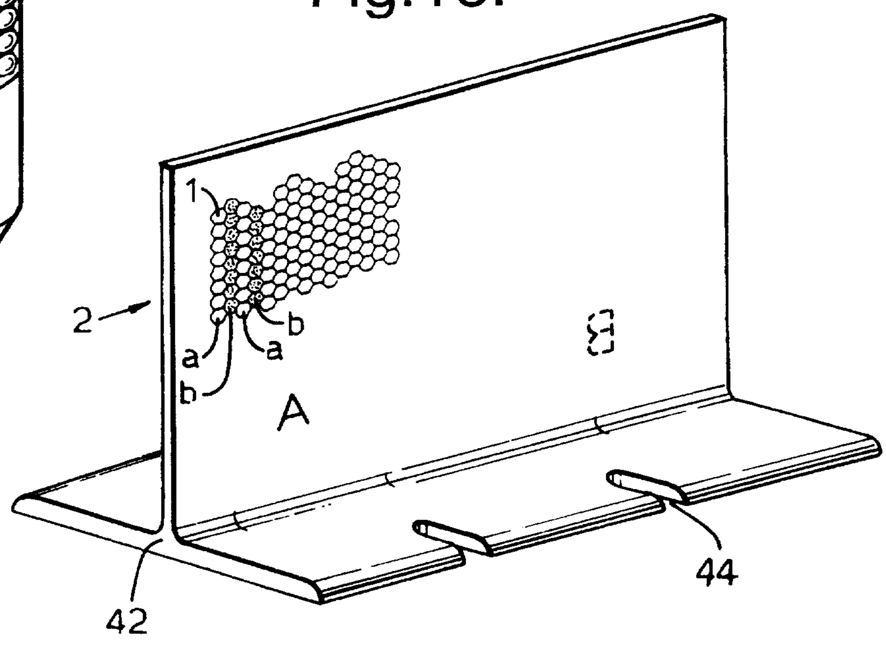


Fig.15.

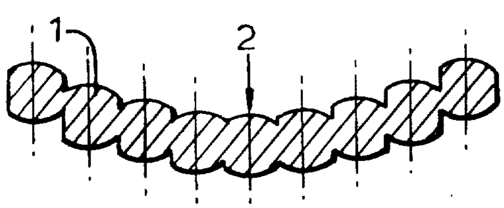


Fig.18.

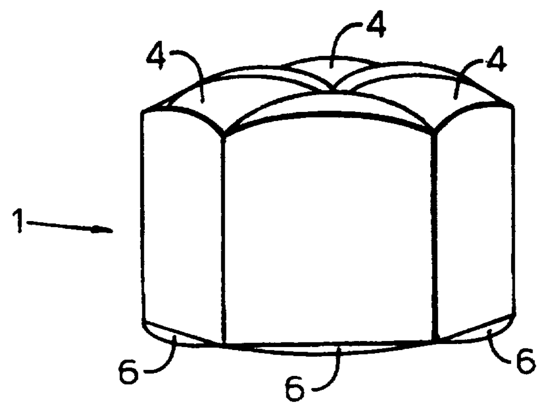


Fig.19.

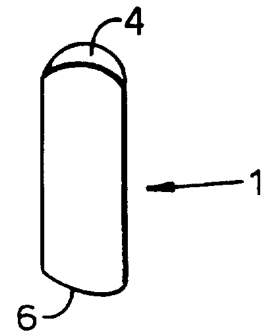


Fig.22.

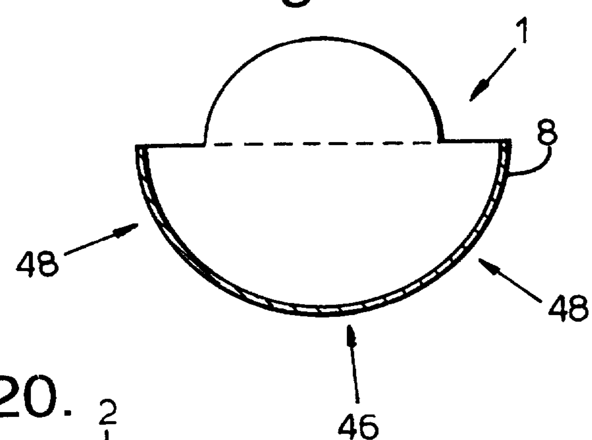


Fig.20.

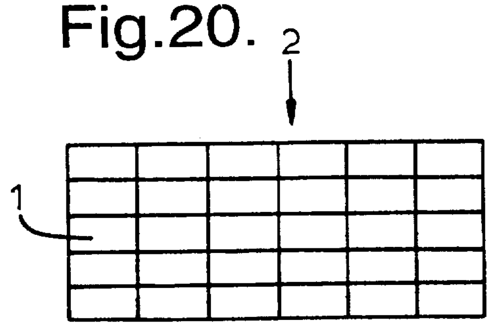
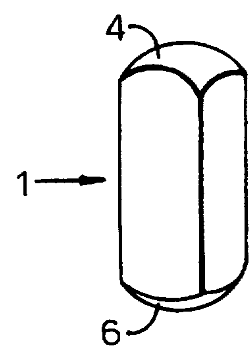


Fig.21.



INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 97/00216

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B5/13 E01F9/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02B E01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 340 301 A (SCHWAB KURT) 20 July 1982	1-5,7, 11-13
A	see column 3, line 48 - line 65 see column 4, line 12 - line 62 see column 5, line 1 - line 6 see figures 1-14 ---	16,18,23
X	US 1 751 984 A (ESKILSON SVEN AUGUST) 25 March 1930	2-5,7
A	see the whole document ---	1,12
X	GB 407 110 A (MACNAB JOSEPH) 5 April 1934	2-5,7
A	see the whole document ---	1,12
A	US 3 580 659 A (FUKUSHIMA YOSHIO) 25 May 1971 see the whole document --- -/--	1-5,7, 12,21

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 September 1997	30/09/1997

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ward, S

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PCT/IL 97/00216

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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